Central Repair Shops --- their size, location and number

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ABSTRACT:

Reports on a method for designing the least expensive central shop system for a Forest Service region. The problem treated is as follows: Consider a region in which a fleet is distributed in a known way. Suppose the decision has been made to establish (or alter) a central shop system for maintenance and repair. How many shops should there be? How big should they be? Where should they be located?

Suppose you decide to set up a central repair shop system to maintain and repair automotive and heavy equipment in a National Forest Region. You know what equipment the Region has and where it is located. But should you build one shop, or more than one? How big? Where? We are developing a method to answer such questions, and this is a progress report on our work.

By a "central shop," we mean one that serves more than one National Forest and that concentrates on repair of heavy equipment and servicing of new vehicles. In this preliminary statement, we report a method of using costs of shop operations and equipment transport to determine the least expensive central system. We give an example of the method, outline the procedure, explain the cost factors involved, and--in an appendix--describe the computations in some detail.

Although we are not trying to answer the question "Is a central shop system desirable?", the procedure described here can be used to compare the economics of maintenance functions with and without a central shop. We realize, too, that management is confronted by decisions on the division of workload between forest and central shops and between Forest-Service-operated and commercial shops. We intend to take up these problems in the future. Before expanding the study, however, we need to test the ideas presented here against actual data and the widest possible variety of criticism. We will welcome comments and inquiries from all who are interested.

METHOD OF ANALYSIS

THE BASIC IDEA

A key concept underlying this study is that changes in the number of shops affects the costs of transport and operations in opposite ways. Thus if we imagine a number of shops so large that every piece of equipment can have a shop depot nearby, then transport costs fall almost to zero, but operations costs would be very high. At the other extreme, if a Region has just one central shop, we would expect operations costs to be at a minimum for the given workload, but transportation costs to be larger. We seek to find the point at which total costs are lowest (fig. 1).

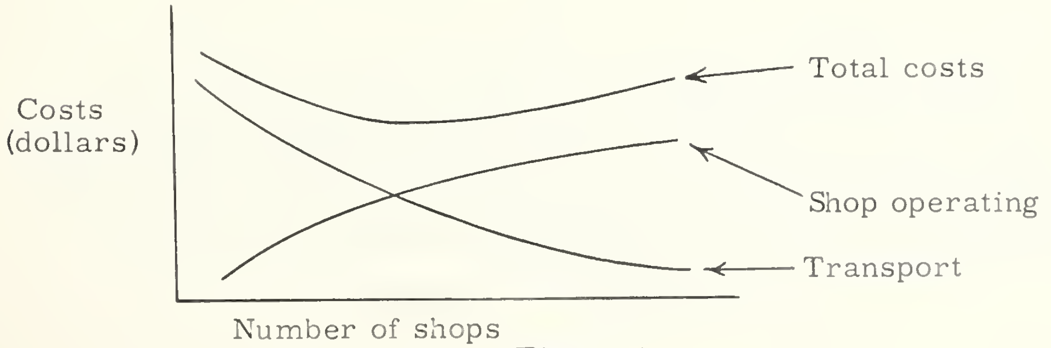

Figure 1

APPLICATION OF THE METHOD

To help explain the method used in this study, we describe here a hypothetical case. A practical situation would involve many complications not included in the example.

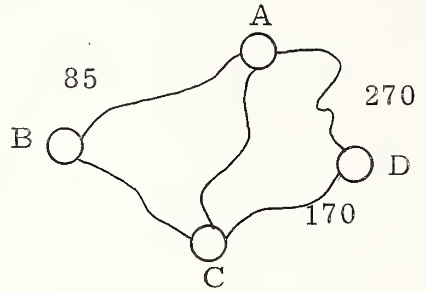

Figure 2

Figure 2 represents a simple case of what a road map might show. The curved lines represent roads; the circles ("nodes") represent towns and/or places where equipment is concentrated. Let us assume, that there is equipment at all four nodes. For simplicity, suppose we have only one class of equipment.

We are interested in the workload for maintenance and repair of the equipment and--for transport costs--how many trips to the shop are made. Suppose this information is available in tabular form (table 1).

Table 1.--Workload from specified sources

Nodes	Workload	Men required	Trips/yr.
	Man-hrs./yr.	Number	Number
A	3,000	2	60
B	6,000	4	120
C	9,000	6	180
D	4,500	3	90

A man-year was arbitrarily set as 1,500 man-hours. The cost of transportation will be 30 cents for each mile. Another item needed is the shortest-route distances between pairs of nodes. From figure 2 this information is obvious. But in a more complicated situation another table would be useful (table 2).

Table 2. --Shortest-route distances between nodes

To/from	Distances			
	A	B	C	D
	Miles			
A	0	85	165	270
B	85	0	115	285
C	165	115	0	170
D	270	285	170	0

The data will suffice for calculating transportation expenses. These expenses are determined by multiplying: (number of trips from a workload source) X (number of miles from the source to its depot) X (transport cost per mile); then adding the results for all sources.

The next requirement is a table showing operating expenses for shops of different sizes (table 3). If we stipulate that equipment always goes to the nearest shop, we are ready to determine specific costs.

Table 3. -- Annual operating costs, by shop size

Shop size (number of men)	Wages	Other (overhead)	Total
	Dollars		
4	24,000	7,000	31,000
6	36,000	8,500	44,500
9	54,000	10,000	64,000
11	66,000	11,000	77,000
15	90,000	12,000	102,000

As a first case, let B and C be the only "feasible" nodes, i.e., places considered suitable for a shop. Suppose we wish to examine the one-depot situation.

Subcase 1. Depot at B. --

Transportation costs:

(A ⟶ B below means traffic from A to B, for example)					Costs
B ⟶ B:			None		
A ⟶ B: (60 trips)X(85 mi.)X($0.30/mi.)	=	$	1,530		
C ⟶ B: (180 trips)X(115 mi.)X($0.30/mi.)	=		6,210		
D ⟶ B: (90 trips)X(285 mi.)X($0.30/mi.)	=		7,695		
Total transportation costs	=	$	15,435	$	15,435
Operations costs: 15 man-shop[1] =102,000			102,000		102,000
Total cost	=	$	117,435	$	117,435

[1]Workload from B = 4 man-yrs./yr.
Workload from A = 2 man-yrs./yr.
Workload from C = 6 man-yrs./yr.
Workload from D = 3-man-yrs./yr.

Total 15

Subcase 2. Depot at C. --

Transportation costs:

C ⟶ C:			None		
B ⟶ C: (120 trips)X(115 mi.)X($0.30)	=	$	4,140		
A ⟶ C: (60 trips)X(165 mi.)X($0.30)	=		2,970		
D ⟶ C: (90 trips)X(170 mi.)X($0.30)	=		4,590		
Transportation total	=	$	11,700	$	11,700
Operations: 15 man depot	=		102,000		102,000
Total cost	=	$	113,700	$	113,700

We see that, for this example, if we are going to have only one depot, and if B and C are the only suitable locations, then costs are lower when the depot is at C.

Now let us examine the two-depot case, and suppose A, B, and C are feasible locations. Then the depots can be at (1) A and C, or (2) A and B, or (3) B and C. The calculation is the same as before, except we must keep in mind that work travels to the nearest depot.

Subcase 3. Depots at A and C. --

Transportation costs:

Depot at A	(A ⟶ A:				None
	(B ⟶ A:	(120)X(85)X($0.30)	=	$	3,060
Depot at C	(D ⟶ C:	(90)X(170)X($0.30)	=		4,590
	(C ⟶ C:		=		None
Total			=	$	7,650
Operations costs:		6 man depot at A			44,500
		9 man depot at C			64,000
Total			=	$	116,150

A serves A and B; therefore, A is a 2 + 4 = 6 man shop. C serves C and D; therefore, C is a 6 + 3 = 9 man depot (see table 1). The workload from B is assigned to A because B is closer to A (85 mi.) than to C (115 mi.). Similarly D is closer to C (170 mi.) than to A (270 mi.).

Subcase 4. Depots at A and B. --

Transportation costs:

Depot at A	$(A \longrightarrow A$:			None
	$(D \longrightarrow A$:	(90)X(270)X($0.30)	=	$ 7,290
	$(C \longrightarrow A$:	(180)X(165)X($0.30)	=	8,910
Depot at B	$(B \longrightarrow B$:			None
		Total	=	$ 16,200
Operations costs:		11 man shop at A		77,000
		4 man shop at B		31,000
		Total	=	$ 124,200

This subcase shows how depot sizes may change with choice of location.

Subcase 5 with shops at B and C is computed similarly and leads to a total cost of $114,620. Thus if the one-depot case and the two-depot case are considered (ignoring the fact that A was not feasible in the first case), we see that a single depot at C would be the cheapest arrangement.

Even when the number of feasible locations and contemplated shops are only moderately large, the number of possible combinations of shop locations can be enormous:

Number of feasible locations = 30

Number of shops assumed = 6

Then there are $\frac{30 \times 29 \times 28 \times 27 \times 26 \times 25}{1 \times 2 \times 3 \times 4 \times 5 \times 6}$

possible location combinations.

One way to handle a case like the example above is to calculate total costs for each combination in turn. The cheapest configuration can be picked out in the process, which we call "combinatorial search."

PROCEDURE TO FIND OPTIMUM CONDITIONS

The method reported in this paper resulted from investigating several approaches, including an attempt to apply mathematical (linear) programming. We concluded that a direct analysis of every combination of shop locations was easiest to use, yet still adequate for problems of the size we expect to encounter. The number of combinations to be

computed by this method may be excessive if the number of shops to be established or relocated as well as the number of possible shop locations is large. Fortunately, in an actual problem for any Region, the number of combinations is greatly reduced by practical considerations which limit the choices of shop locations.

The steps outlined below are intended for the largest problem, i.e., the establishment of a central shop system where none existed before. For many smaller applications, a simpler version with fewer steps will suffice.

In brief, the procedure (fig. 3) is to calculate the transport costs as well as the shop operations costs for every combination of practicable choices of shop locations. The combination producing the lowest total cost yields the number, locations, and sizes we are seeking. If several combinations give nearly the same results, the administrator (Regional Engineer) should decide on the basis of his best judgment. Procedure to be followed in finding optimum conditions is:

1. Determine for the administrative area (e.g. Region) under study the central shop workload, obtaining the number of jobs and man-hours per year for each "source of workload."

2. Reduce the number of workload sources to a manageable size. One way is to select one landmark within each Forest Service Ranger District and assign all vehicles to that point. The actual "source of workload" is the geographical location of each vehicle at the time repair is required (or in the case of new equipment, it is where the vehicle is to be assigned).

3. Draw up a list of the "feasible" locations for depots. A "feasible" location is one characterized by such factors as spare parts availability, adequate labor pool, sufficient transport facilities (including perhaps a railhead), and commercial sources for specialized work.

4. Select an arbitrary number of shops as a starting point, for example, two.

5. Select a trial solution, i.e., arbitrarily assign the shops to some feasible locations. (Omit combinations that would produce excessively high costs.)

6. Calculate the workload for each shop, using the rule that work always goes to the nearest shop. A table of shortest-route highway distances between each source of workload and each feasible location is needed for this and the next step.

7. Compute transport costs for the trial solution.

8. Compute operations costs by using a table similar to table 4, which shows how to compute operating costs for shops of various sizes. The total cost equals the sum of the transport and operations costs.

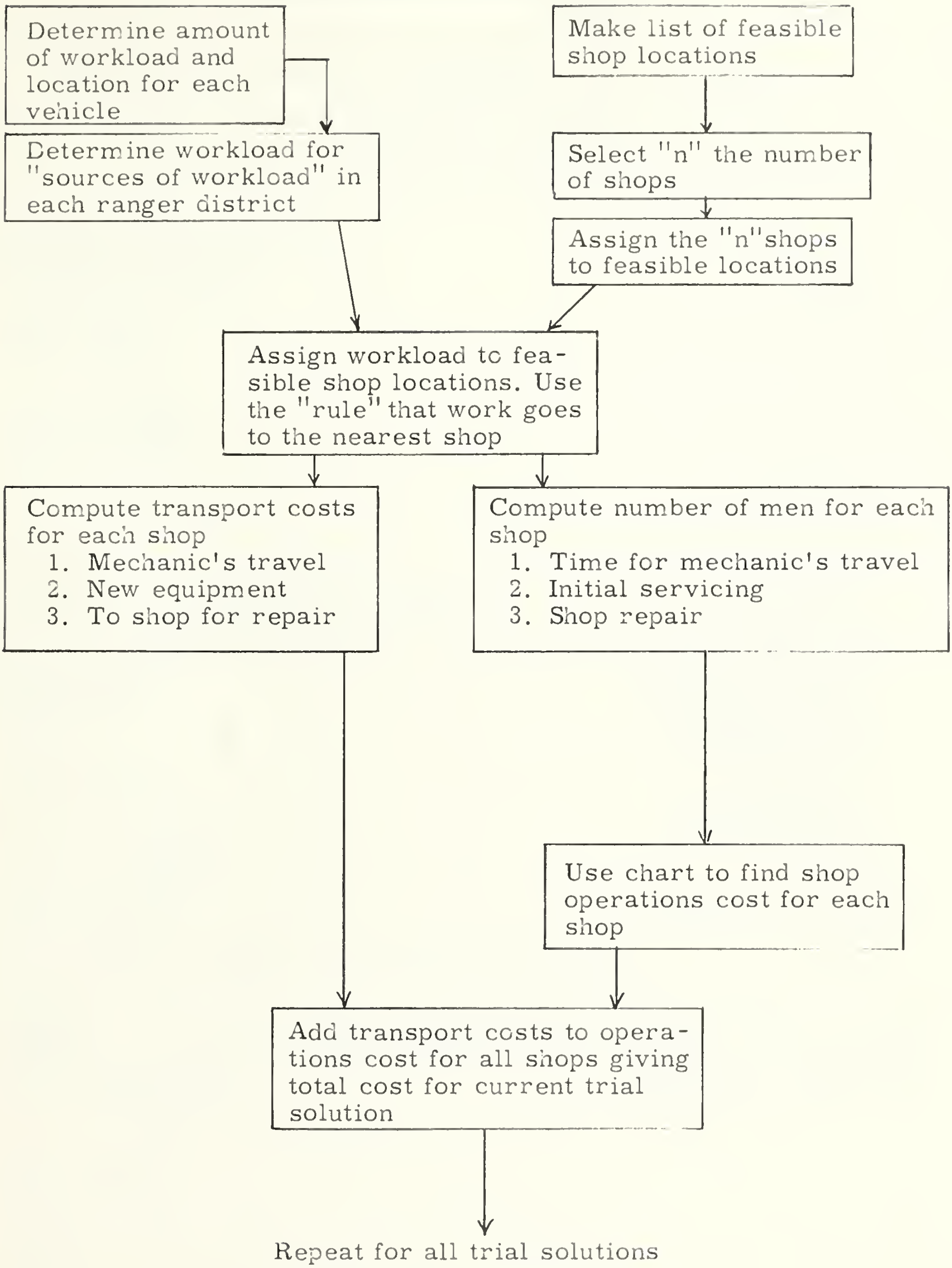

Figure 3.--Schematic diagram of procedure.

Table 4. --Shop operation costs[1]

Types of costs	Shop size, by number of men ("0")							
	1	2	3	4	5	6	--	--
	- - - - - - - - - - - - Men - - - - - - - - - - - - -							
Supervision								
Clerical								
Other								
Total indirect labor:								
Communication								
Rents								
Utilities								
Shop supplies								
Repair of shop equipment								
Expendable tools								
Depreciation of shop equipment[2]								
Depreciation on buildings[2]								
Interest on investments[2]								
Other								
Total shop operation costs								

[1]Format only--values to be assigned by users.

[2]See table 5 for details.

Table 5. --Facilities for different size shops[1]

Facility	Shop size, by number of men ("0")						
	1	2	3	4	5	6	n
	Men						
Shop space, area (sq. ft.):							
Working space per mechanic							
Washing and steam							
Men's room							
Office space							
Parts storage							
Body and paint							
Machine shop							
Lubrication							
Total area							
Total investment in buildings							
DEPRECIATION COST PER YEAR							
Shop equipment							
Hand tools							
Pumps							
Lubrication							
Steam cleaner							
Vacuum cleaner							
Battery charger							
Air compressor							
Medium hoist							
Large hoist							
Crane							
Gages							
Welder							
Pneumatic hammer							
Jack, hydraulic							
Wheel aligner							
Spray paint							
Cutters							
Dies and taps							
Lathe							

Table 5.--Facilities for different size shops[1], continued

Facility	Shop size, by number of men ("0")						
	1	2	3	4	5	6	n
	------------- Men -------------						
Drill press							
Hydraulic press							
Bench grinder							
Valve machine							
Cylinder borer							
Fork lift							
Total investment in shop equipment							
DEPRECIATION COST PER YEAR							
Land							
Area in sq. ft.							
Total investment in land							
Interest							
Total investment in facilities and land							
INTEREST CHARGE PER YEAR ON INVESTMENTS							

[1]For use in determining depreciation on shop equipment, depreciation on buildings, and interest on investments.

9. Select a new trial solution as in step 5 and repeat steps 6 to 9 until total costs for each pair of location combinations have been computed. The pair with the smallest total cost is recorded as the "best" combination.

10. Repeat steps 5 through 9 using a different number of shops, and record the "best combination for each trial solution until all possibilities have been tried.

11. Choose the trial solution that gives the lowest total cost. It is expected that in practice, only a few trial solutions need be examined when the number of feasible shop locations is reasonably small.

COST DETERMINATIONS

Classes of Costs

The procedure for finding the optimum conditions, as previously described, uses the following costs:

1. Transport costs
   a. Transporting equipment to the shop for repair:
      (1) Vehicle utilization (mileage charges).
      (2) Salary of the operator while in transit.
      (3) Movement via commercial carrier (alternative to item (1) and (2) above).
      (4) Unavailability cost due to moving for repair.
   b. Transporting new equipment:
      (1) From manufacturer to the central shops by commercial carrier.
      (2) From central shops to forest shops by forest personnel and by commercial carriers.
   c. Travel by mechanics to equipment in the field:
      (1) Vehicle utilization (mileage charges).
      (2) Unavailability cost due to travel for repair.
      (3) Per diem.

2. Operations costs
   a. Direct labor
      (1) Initial servicing of new equipment.
      (2) Repair of heavy-duty equipment.
      (3) Mechanic's travel.
   b. Indirect labor
   c. Overhead
      (1) Salaries
      (2) Communication, rents, utilities, shop supplies, expendable tools.
      (3) Depreciation on shop equipment, furniture, fixtures, and buildings.
      (4) Interest on investment in land and buildings.

Workload

Management must decide what type and what amount of the total workload is to be done in central shops. To make this decision, we

suggest two methods. The first (historical) method is to examine the file of job and commercial invoices representing a suitable period of time and to classify invoices according to appropriate criteria (e.g., all repair requiring special equipment goes to a central shop). The second (current) method is to code the invoices as they are being filled out and then accumulate the data by automatic data processing. The data also would be classified as field repair or shop work. Either method results in the annual number of jobs and man hours of work together with the location of the vehicle needing service.

Road Network

A network may be defined as a collection of points connected by lines. The points are called nodes, the lines which are not necessarily straight are called arcs. In this study, the roads as shown on a road-map form a network. We consider the roads arcs and junctions nodes. Sources of workload are also considered nodes.

Provided we assume transportation costs are proportional to distance and to volume of traffic, it follows that transportation costs can be minimized when shops are located at nodes. As proof of this, consider a shop located on an arc between the adjacent nodes A and B. With volume of traffic in terms of cost per mile, let A be the direction from which traffic is heavier. By moving the shop toward A, the total transport costs are reduced. As a consequence of the rule that the workload is always assigned to the nearest shop, it might happen that moving the shop toward A changes the assignment of work coming from B to some other shop nearer the source. This change would reduce the traffic from B. Similarly, traffic from A might be increased. In either case, continued reduction in the transport cost occurs. Thus, we need not consider the possibility that shops be located between nodes.

The table of shortest-route highway distances mentioned elsewhere can be made up by referring to a road map and considering only those roads suitable for transporting heavy vehicles.

Following is an example of reducing the number of "sources of workload" to a manageable size. Suppose that in a hypothetical section of a district we found that vehicles were distributed according to figure 4. The numbers in boxes represent the number of vehicles

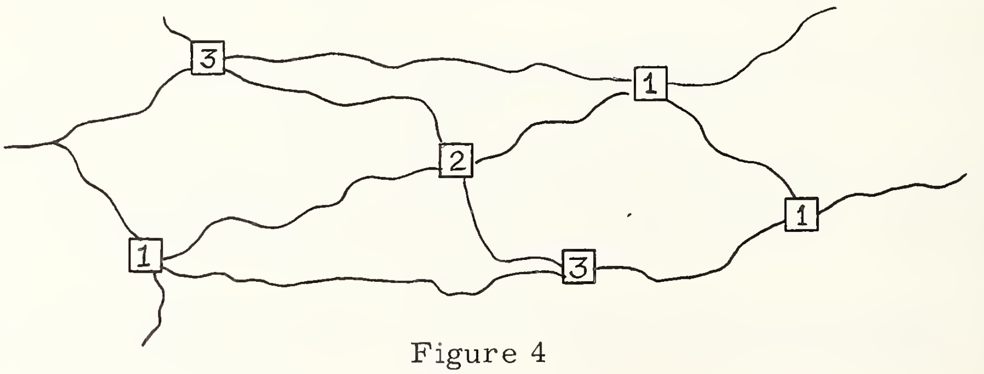

Figure 4

that operate from stations shown by the boxes. The lines represent the roads connecting the stations. By assigning all 11 vehicles to the station indicated by $\boxed{2}$, we introduce only a small error but considerably reduce the complexities of computation.

Transport

Vehicle utilization. --These costs are not the same as working capital fund rental rates. The rental rates include provisions for overhead expenses as well as expenses which increase in proportion to vehicle usage. Hence, vehicle utilization costs should be so calculated that only costs proportional to usage are included. A reasonable approximation to these costs can be calculated by considering only operations costs, such as fuel, tires and tubes, and maintenance costs due to equipment usage. These costs will be used in computing equipment moving cost per mile. They are to be developed by the user from his fleet management accounting data (table 6).

Movement by commercial carrier. --These costs can be found from the State Public Utilities Commission tariffs, U. S. Interstate Commerce Commission tariff, or private trucking companies.

Unavailability cost. --When equipment in need of repair is unavailable to the forest, the Forest Service often incurs costs. The true costs resulting from delays in work, idle crews, and other causes are impossible to calculate accurately. Elapsed delay time consists of three parts: (a) time required to transport a mechanic to the field or the equipment to the shop, (b) repair time, and (c) shop waiting time. Shop waiting time may be ignored because the bulk of shop-type work is scheduled. (Throughout this report we have ignored problems of delay, or queuing, owing to congestion of shop facilities.) Repair time is assumed to be constant for any shop location. This leaves travel and transport time--the true value of which is tenuous. Therefore, we assumed the value of delay due to travel and transport time to be the same as the cost of a temporary substitute vehicle. This is a safe assumption because unavailability costs are but a small part of the total shop system cost, and we are introducing only a small error by this approximation.

To estimate the unavailability cost per hour, two methods have been suggested: (a) use an average cost for leasing substitute equipment; or (b) use the following formula:

$$\text{Initial cost} \div \{\text{years of life of equipment x average hours used per year}\}$$

Either method may be employed by management to construct a schedule of unavailability cost per hour similar to table 7.

Transporting new equipment. --The costs of transporting equipment from the manufacturer to a General Services Administration delivery point and thence to a central shop are paid by the Forest

Table 6. --Schedule of variable costs of vehicle utilization[1]

Equipment class	Utilization cost/mile "C"

[1]For heavy equipment moved on a tractor semi-trailer, use the tractor semi-trailer rates.

Service as part of the purchase price. For different trial solutions, choose the GSA delivery point that produces the lowest transport cost.

For costs of transporting between factory and GSA delivery point, management can refer to GSA contract terms.

For transporting between GSA delivery points and central shops and between central shops and forest headquarters, management should list the costs in a table similar to table 8. For each entry, select either the commercial tariff or an estimate of mileage and the driver's salary cost for transporting by National Forest personnel. If both methods are used for a given district, use a weighted average of the costs of both methods.

Table 7. --Schedule of the cost/hour for computing unavailability cost[1]

Equipment class	District									
	1	2	3	4	5	6	7	.	.	.[2]
010 Sedan										
011 Compact										
020 S. Wagon										
.										
.										
.										

[1]Format only--values to be assigned by each Region.

[2]Columns to be added as needed.

Mechanic's travel. --The costs for a mechanic's travel are the operating cost for his vehicle plus per diem, if any; his salary is included in operations costs. When a mechanic cannot return to his shop within normal working hours, he is obliged by regulations to stay overnight even though his travel time may be very small. For any given trip the travel time may differ from one trial solution to another--resulting in a change in per diem costs and in the other travel costs. Operations costs, therefore, are not entirely independent of shop location because the number of men needed depends to some extent on the amount of time which mechanics spend in travel.

Shop Operations

Table 4 illustrates shop operation costs for various shop sizes. The table can be modified to suit local conditions. The entries for the table should be developed by using fleet management accounting data and engineering estimates. The shop size is expressed in terms

of the number of men necessary to handle the workload; the number of men is computed by the method shown in the appendix. To estimate the savings in operations costs obtained by consolidating a forest shop with a central shop, use the table and compare the costs of independent operations with the costs of a consolidated operation.

Some operating costs are closely related to the total fleet size, the structure of the administrative organization, or the degree of assistance given fleet management by personnel at each National Forest headquarters. These total costs will remain essentially the same even though shop sizes and locations change. Consequently, they are excluded from our method because they would not be affected by the outcome of the calculations. Examples of excluded costs include personal travel expenses, allocated overhead, most clerical functions, inventory obsolescence, and fleet management.

Old equipment. --The analysis does not include preparing old equipment for sale because it is an optional central shop function which appears to be of small economic importance (about 2 percent of Region 5 central shop workload).

Table 8. --Cost of moving new vehicles from GSA delivery point to central shop or from central shop to depot[1]

Cities of destination	Cities of origin												
	Arcadia	Bakersfield	Del Rosa	San Bernardino	Fresno	Marysville	Merced	Modesto	Redding	Sacramento	San Francisco	Stockton	Tulare
	Costs												
Alturas	102.75	83.75	105.91	105.91	68.00	41.00	61.50	55.50	27.50	46.00	58.75	50.00	74.00
Arcadia	--	24.50	15.00	14.00	36.25	64.50	43.25	49.25	77.50	58.75	61.50	52.00	31.50
Bakersfield	24.50	--	28.75	28.75	22.00	46.00	26.50	31.50	58.75	41.00	43.25	34.00	17.50
Bishop	41.00	36.25	38.25	38.25	49.25	77.50	55.50	61.50	89.75	71.00	74.00	64.50	43.25
Del Rosa	15.00	28.75	--	7.75	43.25	68.00	49.25	52.00	83.75	61.50	68.00	58.75	36.25
San Bernardino	14.00	28.75	7.75	--	41.00	68.00	49.25	52.00	83.75	61.50	68.00	55.50	36.25
Escondido	22.00	36.25	20.75	20.75	49.25	77.50	55.50	61.50	93.25	71.00	74.00	64.50	43.25
Eureka	99.00	80.50	105.91	102.75	68.00	46.00	58.75	55.50	31.50	46.00	46.00	52.00	71.00
Fresno	36.25	22.00	43.25	41.00	--	34.00	16.00	20.75	46.00	27.50	31.50	22.75	15.00
Marysville	64.00	46.00	68.00	68.00	34.00	--	26.50	22.75	22.00	15.00	24.50	20.75	38.25
Merced	43.25	26.50	49.25	49.25	16.00	26.50	--	12.75	41.00	21.50	25.25	17.50	21.50
Modesto	49.25	31.50	52.00	52.00	20.75	22.75	12.75	--	36.25	19.25	22.00	11.25	24.50
Mt. Shasta	89.75	71.00	93.25	93.25	55.50	31.50	49.25	43.25	19.75	36.25	46.00	41.00	61.50
Placerville	61.50	43.25	68.00	68.00	31.50	19.25	25.25	21.50	30.00	15.00	26.50	19.75	36.25
Porterville	31.50	16.00	36.25	34.00	19.25	41.00	22.75	26.50	55.50	36.25	38.25	30.00	11.25
Quincy	80.50	61.50	83.75	83.75	46.00	22.75	41.00	36.25	27.50	27.50	38.25	34.00	52.00
Redding	77.50	58.75	83.75	83.75	46.00	22.00	41.00	36.25	--	26.50	36.75	31.50	52.00
Sacramento	58.75	41.00	61.50	61.50	27.50	15.00	22.00	19.25	26.50	--	22.00	15.00	31.50
San Francisco	61.50	43.25	68.00	68.00	38.25	24.50	25.25	22.00	36.25	21.50	--	21.50	36.25
Sonora	55.50	38.25	61.50	58.75	24.50	25.25	20.75	22.75	38.25	20.75	26.50	19.25	30.00
Stockton	52.00	34.00	58.75	55.50	22.75	20.75	17.50	11.25	31.50	15.00	21.50	--	27.50
Susanville	86.75	68.00	93.25	93.25	55.50	28.75	46.00	43.25	27.50	34.00	46.00	41.00	61.50
Tulare	31.50	17.50	36.25	36.25	15.00	38.25	21.50	24.50	52.00	31.50	36.25	27.50	--
Weaverville	86.75	68.00	93.25	89.75	55.50	28.75	52.00	43.25	17.50	34.00	43.25	38.25	58.75
Willows	68.00	49.25	74.00	74.00	36.25	16.00	31.50	26.50	19.25	19.75	27.50	23.50	43.25
Yreka	93.25	74.00	99.00	99.00	61.50	36.25	55.50	49.25	22.75	41.00	52.00	46.00	68.00
San Leandro	58.75	41.00	64.50	61.50	27.50	23.50	22.00	19.75	36.25	21.50	12.75	19.25	34.00
Van Nuys	11.25	22.75	19.25	19.25	34.00	61.50	41.00	46.00	74.00	55.50	58.75	49.25	28.75

[1]Values obtained from California Public Utilities Commission (assumes three trucks per load).

APPENDIX

COMPUTATIONS

Central Shop Operation Cost

The number of men for a given shop workload may be determined as follows:

Let:

J = Number of man-hours/year for initial servicing for a given forest.
P = Total man-hours for repair for a given district.
H = Number hours/year of useful time for repair per man.
Z = Number of trips between a given district and the nearest central shop.
D = Distance to a given district from the nearest central shop.
V_1 = Velocity of mechanic's travel to work site.
M = Total man-hours spent in travel between a given district and the nearest depot and is given by:

$$M = Z \cdot \frac{2D}{V_1}$$

Then the number of men for a given shop is "0" and is found by computing:

$$0 = \frac{1}{H} (J + P + M)$$

for each district and summing over all the districts which send work to a given shop.

Use "0" and table 4 to find the operating cost.

The sum for all shops is the total shop operations cost.

Cost of Travel by Central Shop Mechanics

The costs for a mechanic's travel are the operating costs for his vehicle plus per diem, if any.

Computation of these costs may be made by using the following:

Let:

K = Vehicle cost/mile for mechanic's truck.
P = Per diem cost for every 6-hour period of total trip time.
V_1 = Velocity of mechanic's travel to work site.
D = Distance to the district from the nearest central shop.
B = Hours spent in actual repair work at the site of equipment breakdown.
n = The number of per diem units.

n* = The number of per diem units n rounded off upward to integer value in which:

$$n = \left\{\frac{1}{6} \quad B + \frac{2D}{V_1}\right\}$$

f = Per diem cost per trip = n* P.
g = Mileage cost per trip = 2D K.
h = Combined cost per trip = n* P + 2D K.
i = Total annual cost for mechanic's travel for a given shop.
j = Total annual cost for mechanic's travel for all shops.

Then:

i = Sum of h for all trips (for a given shop).
j = Sum of i for all shops.

The man-hours for repair in the Forest Service's Region 5, as shown on ADP reports, include the time mechanics spend in travel. In order to use actual data from Region 5, travel time must be separated from the total. This procedure requires a separate computation using data obtained by sampling the daily time slips. (See instructions on Estimating the Number of Hours for Repair Excluding Mechanic's Travel).

<u>Cost of Transporting Equipment to Central Shop for Repair</u>

These costs are determined by either of the following formulas:

Let:

W = Number of items of a given class of equipment in a given district.
N = Number of trips per year for pieces of equipment of that class which are moved from the district to the nearest central shop.
$\bar{n}$ = Average number of trips per year per item for equipment of a given class which is moved from the district to the nearest central shop.
D = Distance from the district to the nearest central shop via the shortest route (one-way).
C = Cost per mile to move equipment of that class from the district.
y = The annual cost to move a given class of equipment from a given district to the nearest central shop for repair.
Y = Total annual cost to transport equipment to central shops for repair.

(1) $y = NDC$

(2) or $y = W\bar{n}\,DC$

Y = Sum of y for all classes and all districts.

Equipment Unavailability Costs

While equipment is out of service for repair or is being transported, it is unavailable for use. We can compute these costs as follows:

Let:

A = Unavailability cost per hour for a substitute unit of a given class on a given district (table 7).

V_2 = Average speed of transporting equipment to a shop for repair.

V_1 = Average speed of transporting a mechanic to the equipment site.

D = Distance from a given district to the nearest central shop.

N = Frequency in number of trips per year made by a given class of equipment from a given district into the shop for repair.

X = Frequency in number of trips per year made for a given class of equipment in a given district by mechanic traveling to the district.

a = Total annual unavailability cost for moving equipment to shop for repair.

b = Total annual unavailability cost while moving the mechanic to the district.

c = Total annual unavailability cost.

a = Sum of $2 \frac{A}{V_2} D N$ for all districts and classes.

b = Sum of $\frac{A}{V_1} D X$ for all districts and classes.

c = Sum of $AD \left\{ \frac{X}{V_1} + 2\frac{N}{V_2} \right\}$ for all districts and classes.

Estimating the Number of Hours for Repair Excluding Mechanic's Travel

Values shown on ADP reports of man-hours for repair contain mechanic's travel time and repair time. To compute the workload for each district for actual repair only, the ADP values must be adjusted. Data for Z and E (below) may be obtained from daily time slips.

Let:

F = Sum of all tabulated man-hours base period, a given district obtained from ADP (includes repair as well as travel).

Z = Number trips/year to a given district from the associated shop.

V_1 = Velocity of travel (mi./hr.) by mechanics.

E = Distance (one-way) to a given district from associated shop.

P = Annual man-hours for repair for a given district, excluding travel and initial servicing,

$$P = F - \frac{2E\,Z}{V_1}$$

Transporting New Equipment

Let:

S = Average cost per unit to transport new equipment to a given central shop (assuming delivery is from the nearest GSA delivery point).

T = Average cost per unit to transport new equipment to a given district from the nearest central shop.

U = Number of units of new equipment per year delivered to a given district.

d = Then the total cost of transporting new equipment to and from a given central shop = sum of U(T + S) for all districts associated with a given shop.

e = Total cost of transporting new equipment for all central shops = sum of d for all shops.